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RECENT EXPERIENCE WITH ENSEMBLE STREAMFLOW PREDICTION IN THE DES MOINES RIVER BASIN

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1. INTRODUCTION

An ensemble streamflow prediction system which provides probabilistic hydrologic forecasts with lead times of a few days to several weeks is now operational for the Des Moines River basin, Minnesota/Iowa. These forecasts not only account for precipitation already on the ground but also account for estimates of future precipitation. This prediction system greatly improves the capability to take timely and effective actions that will significantly mitigate the impact of major floods and droughts. The system also provides better overall information for use in managing competing water demands for multiple water users, e.g., agriculture, ecosystems, hydro-power and navigation. The system uses operational precipitation forecast products, including long-range probabilistic products that are produced by the National Weather Service, National Centers for Environmental Prediction. This paper presents an overview of the system, reviews recent forecast experience, and introduces advancements towards future ensemble forecasting trends.

2. ENSEMBLE FORECASTING DEFINED

The NWS River Forecast Centers (RFCs) typically issue deterministic stage forecasts for a few days into the future. These forecasts are primarily produced with only historical and real-time data; in some cases 24 hour quantitative precipitation forecasts (QPFs) are also used in order to increase lead times of real time forecasts. For increased lead times from days to weeks, it is critical to include future temperature and precipitation forecasts at all time scales out to seasonal. Enhancements to river forecasting include the combined use of deterministic and probabilistic procedures through Monte Carlo type simulations, i.e., the Ensemble Streamflow Prediction (ESP) technique (Day, 1985) of the National Weather Service (NWS).

ESP is one significant portion of the NWS River Forecast System (NWSRFS) as it produces an ensemble of possible streamflow hydrographs which can be analyzed using standard statistical techniques to generate forecasts. ESP is run to produce an ensemble of equally likely to occur stages for each forecast point. ESP, in it's basic form, assumes that historical meteorological data are representative of possible future conditions and uses these as input data to hydrologic models along with the current states of these models obtained from the forecast component of the NWSRFS. A separate streamflow time series is simulated for each year of historical data using the current conditions as the starting point for each simulation. The streamflow time series for each year's simulation can be analyzed statistically for peak flows, minimum flows, flow volumes, etc., for any future time period to produce a probabilistic forecast for the streamflow variable. This analysis can be repeated for different forecasts periods and additional streamflow variables of interest. Short-term quantitative forecasts of precipitation and temperature can be used to weight the years of simulated streamflow based on the similarity between the climatological conditions of each historical year and the current year. ESP allows flexibility in the streamflow variables which can be analyzed, the capability to make forecasts over both short- and long-time periods, and the ability to incorporate forecast meteorological data into the procedure.

3. DES MOINES RIVER BASIN -- ESP FORECASTS

The Des Moines River basin was selected as the first operational site for these long-range probabilistic forecast products following the devastating impacts of the "Great Flood of 1993" (NWS, 1994) which included severe flooding in and around Des Moines, Iowa and along the Racoon River, an unregulated tributary to the Des Moines River.

The Des Moines River is regulated for flood control by Saylorville and Red Rock reservoirs by the U.S. Army Corps of Engineers. They are operated together to provide both flood protection at key downstream locations and low flow for water supply and water quality control. Recreation as well as fish and wildlife are secondary benefits. One of the primary objectives of this project was to provide probabilistic forecasts of the flows into these reservoirs and the river stages downstream.

Implementation of this advanced forecasting system for the Des Moines River basin began in 1995; it has been operational since March 1997. The

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functionality and associated implementation activities for the total system include:

- provide advanced hydrometeorologic/hydrologic modeling procedures that better account for the natural and man-made complexities of local river basins;

- implement the NWS Ensemble Streamflow Prediction (ESP) procedure in order to provide probabilistic hydrologic forecasts into the future from days to months;

- couple meteorologic forecasts and climate predictions within the ESP procedure; include the effect of reservoir operations in both short-term and long-term forecasts;

- implement dynamic streamflow modeling in river reaches with significant dynamic effects caused by backwater, levee overtopping, or other transient phenomena; and,

- provide advanced products (e.g., probability of occurrence information and inundated area mapping) for flood mitigation and water resources management activities to other federal, state and local organizations.

3.1 COMPUTATION OF ESP FORECASTS

Forecasts distributed for the Des Moines River basin are computed using enhancements to the original ESP technique. The original ESP technique is part of the NWS operational flood forecasting system called the NWS River Forecast System (NWSRFS).

The ESP technique used for the Des Moines incorporates QPFs and climate predictions; referred to as meteorologic/climate coupling. The method consists of adjusting historical mean-areal precipitation and temperature time series relative to current meteorological outputs/climate outlooks prior to using them as input to the hydrologic models (Perica, 1998). The adjustment is based on the comparison of coinciding marginal exceedence probabilities of historical records and climate outlooks. The daily adjustment coefficients, λ, were calculated from the 1- to 5-day NWS Hydrometeorological Prediction Center (HPC) precipitation and temperature forecasts, the 6- to 10-day NWS Climate Prediction Center (CPC) precipitation and temperature forecasts, the 1-month climate outlook from CPC, and the seasonal climate outlooks from CPC. The Des Moines WSFO produced the 24-hour QPFs that were also blended into the ESP forecasts.

A significant contribution of ensemble forecasting, in contrast to deterministic forecasts, is the resulting capability to assess "what if" scenarios using the resulting exceedence probability information. For example, should a flood fight be eminent and the question be raised regarding the height to which sand bags should be placed, the answer can be derived with consideration of ESP products. Using this type of a real-time generated product, along with existing deterministic forecasts, an elevation which corresponds to an acceptable level of risk may be selected. This same type information may be incorporated in other applications as well, e.g., maximizing hydropower production.

3.2 Description of ESP Forecast Products

In order to convey model output and information to users it was necessary to develop the ESP Analysis and Display Program (ESPADP). Two enhancements resulted from ESPADP: 1) a model analysis procedure and product generator leading to greater abilities to present probabilistic products for water resource managers, and 2) the provision of interactive graphical displays for both hydrologic forecasters and users to maximize their ability to understand and interpret ESP output. Hydrologic products have typically been tabular in nature and limited to short time frames. These new graphical products are able to pass on greater amounts of data and information for longer periods of time; e.g., ESP probability interval and exceedence probability plots. The need for such products with more information has been voiced by water resource managers after all major flood disasters since the Great Flood of 1993.

Another significant product which utilizes real-time ESP output data is a flood inundation map. The inundation map depicts the probabilities that specific areas around the city of Des Moines, Iowa will be flooded during the identified 60-day period. The map does not give information about flood depth above the ground, river stage, or flood return interval and is not related to any hypothetical 25-, 50-, or 75-year return-interval flood. The inundation map is based on the best digital elevation model (DEM) data available. If a DEM of greater resolution and accuracy becomes available, it can be used with the demonstration software and procedures to produce a more accurate flood inundation map based on the NWS hydrologic forecasts.

In order to spatially display a range of inundation probabilities for a specified future window of time, ESP is run to produce an ensemble of stages for each forecast point. For each streamflow hydrograph, the NWS dynamic streamflow routing model, FLDWAV (pronounced "flood wave"; Fread and Lewis, 1988) is run in order to route the flow and determine the associated river elevations occurring at the cross sections specified between the forecast points. An analysis of this array of water surface elevations is then performed using ESP, resulting in a data set which provides predicted river elevations for each cross section and for multiple probabilities of exceedence. Therefore, ESP generated data, FLDWAV and GIS technologies provide for a spatial display of either inundation depths or probabilistic contours (zones) of inundation for a specified future window of time.

4. ESP FORECAST VERIFICATION

Since the beginning of these advanced operations for the Des Moines River basin, March 1997, only a few minor flood events have occurred. For those events which did occur, the 50 percent exceedence probability stage was as close or closer to the final observed crest than traditional outlook products (NWS, 1997). Keeping in mind, operational verification is not sufficient with limited data sets, additional data for future events will be gathered and examined.

Verification of ESP forecasts is difficult due to their probabilistic nature, and, comparison of a single ESP forecast with the observed values for a given period is not a sufficient test of the quality of that forecast. A better test of ESP forecasts is to examine a distribution of many ESP forecast traces and compare the statistics of that distribution with the distribution of the corresponding observations. This type analysis will be conducted for future flow events using the recently developed ESP Verification System (ESPVS).

5. THE NEXT STEP — NEAR-TERM PROBABILISTIC FORECASTS

The NWS is now enhancing the ESP technique to more directly include NWS meteorologic and climatologic forecasts in the near-term. The goal to be achieved with this coupling is to predict future streamflows and river stages as accurately as possible, and at the same time quantify the uncertainty in the forecasts.

For this objective, different sources of meteorological forecasts are used as input to produce the future precipitation ensemble. WFO forecast information is emphasized for the near-term (one to three day) time frame. At the present, this is a deterministic QPF forecast; probabilistic QPFs (PQPFs) are being developed and will be used in the future (Schaake and Larson, 1998 and Adams, et. al., 1999). These PQPFs will control an ensemble precipitation processor that will generate ensemble members which account for hydrologically relevant space/time variability using historical precipitation to help limit extreme occurrences. For the long-range time scale, ensemble members depend on probabilistic products from the Climate Prediction Center (CPC) that are used to rescale historical precipitation events. In the intermediate range, techniques are being developed to make use of ensemble products that will be produced by different NCEP models over the full range of time scales, with appropriate adjustment to remove biases using historical precipitation and with additional modifications by forecasters.

The precipitation ensemble required by NWSRFS is produced by an Ensemble Precipitation Processor (EPP) that assimilates short-term probabilistic quantitative precipitation forecasts (PQPF) provided by field forecasters at WFO's as well as long term PQPF provided by forecasters and forecast models at the National Centers for Environmental Prediction (NCEP). Required information about the spatial and temporal correlation structure of precipitation is derived directly from climatology and by analysis of numerical model gridded products. The EPP is one part of an RFC Precipitation Analysis System (PAS) that is operated at the RFC as part of the Hydrometeorological Analysis and Support (HAS) function.

6. UPPER MONONGAHELA DEMONSTRATION PROJECT

A key part of the development and implementation strategy for these new ESP products is to conduct pilot projects to demonstrate the value of the forecasts and to reduce the risks associated with implementing the techniques elsewhere. Des Moines operations initially began as a demonstration for the spring snowmelt season of 1997. Another demonstration is just beginning in the Upper Monongahela River Basin, West Virginia. In the Des Moines basin, the forecast period of interest was 60 days and the focus was on spring snowmelt runoff. In the Monongahela basin, the immediate objective is to use Probabilistic Quantitative Precipitation Forecasts (PQPF) produced by forecasters at Weather Forecast Offices (WFO's) to produce 1-3 day lead time Probabilistic River Stage Forecasts (PRSF's; Adams, et. al., 1999).

7. CONCLUSIONS

The Des Moines forecasting system has been very successful in that all major implementation goals were met. However, as an initial effort, there remain areas where improvements can be made. Some observations and recommendations follow:

- ESP spring flood outlook values, particularly at the 50 percent probability of exceedence level, compared well to traditional forecast techniques in areas where snowmelt flooding occurred. Furthermore, these probabilistic products gave significantly more information to the users.
- Users of these new products, both external to and within the NWS, generally said the new product formats were very useful and contained additional information. Lack of flooding activity during the demonstration reduced interest by some users, especially external users.
- Inundation mapping was successfully demonstrated for the city of Des Moines, Iowa (Fread, et. al., 1998).

- The use of an Internet home page for outside user access has proven to be very successful. The home page at WSFO Des Moines is still in use and can be accessed at:

  http://www.crh.noaa.gov/dmx/ahps

  ESP products appearing at this site are presently updated in conjunction with CPC updates; the products would be updated more often as the hydrologic situation in the Des Moines basin dictates. The use of the internet opens up an entirely new and easy access of NWS products by users.

- The use of QPF and climate products (1- to 5-day, 6- to 10-day, 30-day, and seasonal) are extremely useful. The ESPADP-generated forecast products (stage, flow, and volume) out to 60 days has been used by external users and proven to be extremely useful.

- It is recognized that additional operational verification data must be developed and analyzed.

- Additional training resources need to be developed for the interpretation and understanding of the statistical products and procedures.

- ESP is an important approach to river forecasting, because it can provide consistent probabilistic information about the joint occurrence of events at multiple locations in a river basin. This is an extremely important feature for decisions involving the operations of systems of reservoirs, downstream diversions and downstream flood prone areas. These activities clearly show the benefits of probabilistic-type products.

- The use of PQPFs should be reviewed in order to further advance the ability to forecast river stages as accurately as possible, and at the same time quantify the uncertainty in the forecasts.

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